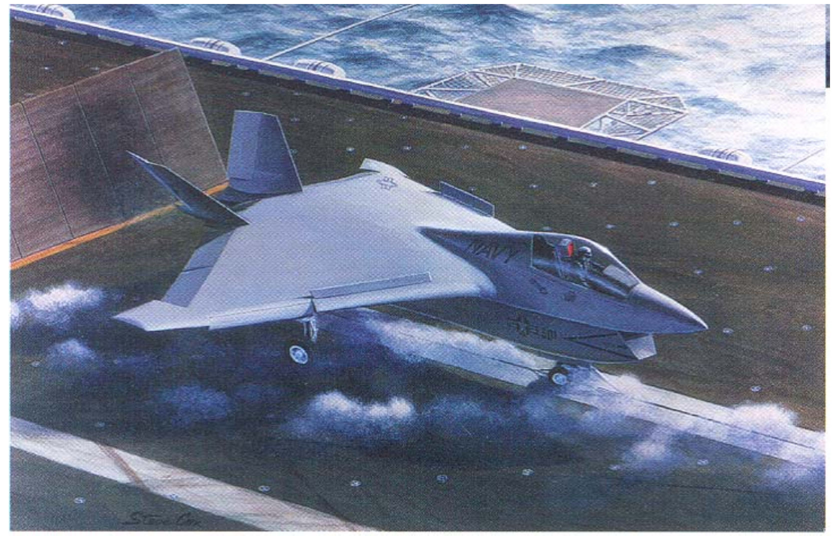
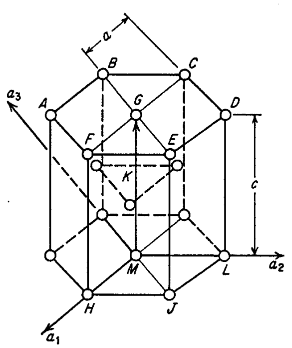
NRC · CNRC

In-Situ Intergranular Strain Accumulation in a Titanium Alloy Polycrystal





Basal plane (0001) – *ABCDEF*
Prism plane $(10\bar{1}0)$ – *FEJH*
Pyramidal planes
Type I, Order 1 $(10\bar{1}1)$ – *GHJ*
Type I, Order 2 $(10\bar{1}2)$ – *KJH*
Type II, Order 1 $(11\bar{2}1)$ – *GHL*
Type II, Order 2 $(11\bar{2}2)$ – *KHL*
Digonal axis $[11\bar{2}0]$ – *FGC*

Kelly T. Conlon
Neutron Program for Materials Research
National Research Council of Canada

1st ACNS Conference, June 24 2002

Outline

- Intergranular Strains in Polycrystals
- Deformation of Hexagonal Close Packed Metals
- Neutron Diffraction Experiments
- Modelling Results vs. ND Results
- Summary

Collaborators

- Roger Reed (University of British Columbia)
- David Dye (National Research Council of Canada)
- J-R. Cho, Howard Stone, Cathy Rae (Cambridge University)
- Mark Daymond (ISIS – Rutherford Appleton Laboratories UK)

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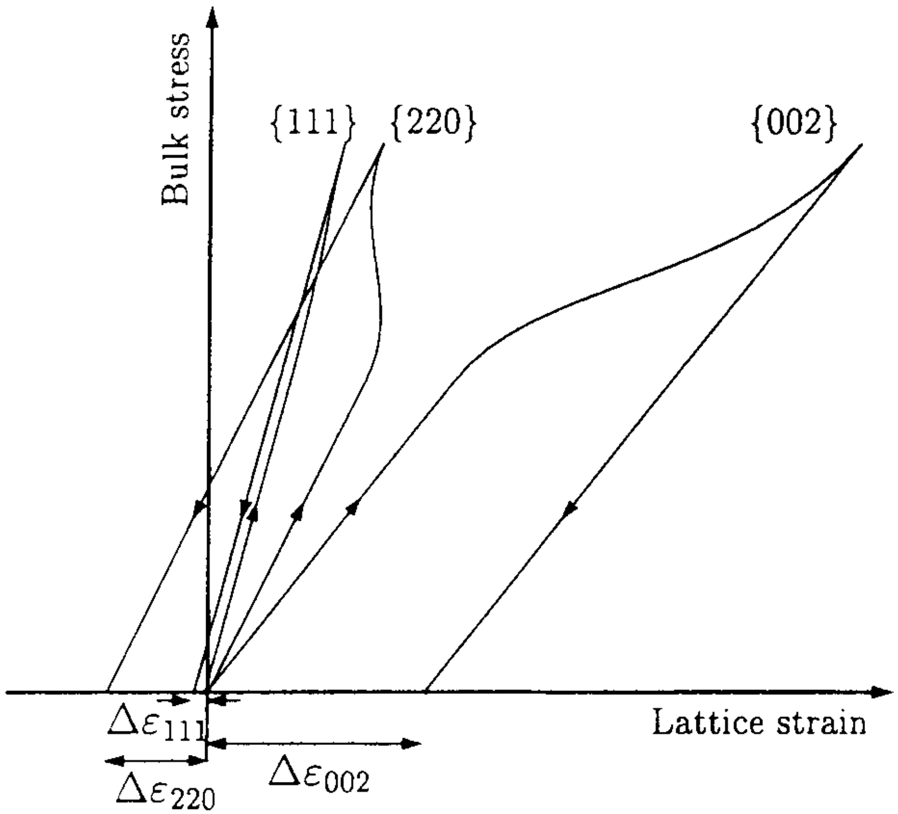
NRC/British Council Joint S&T Fund

Rolls Royce plc.

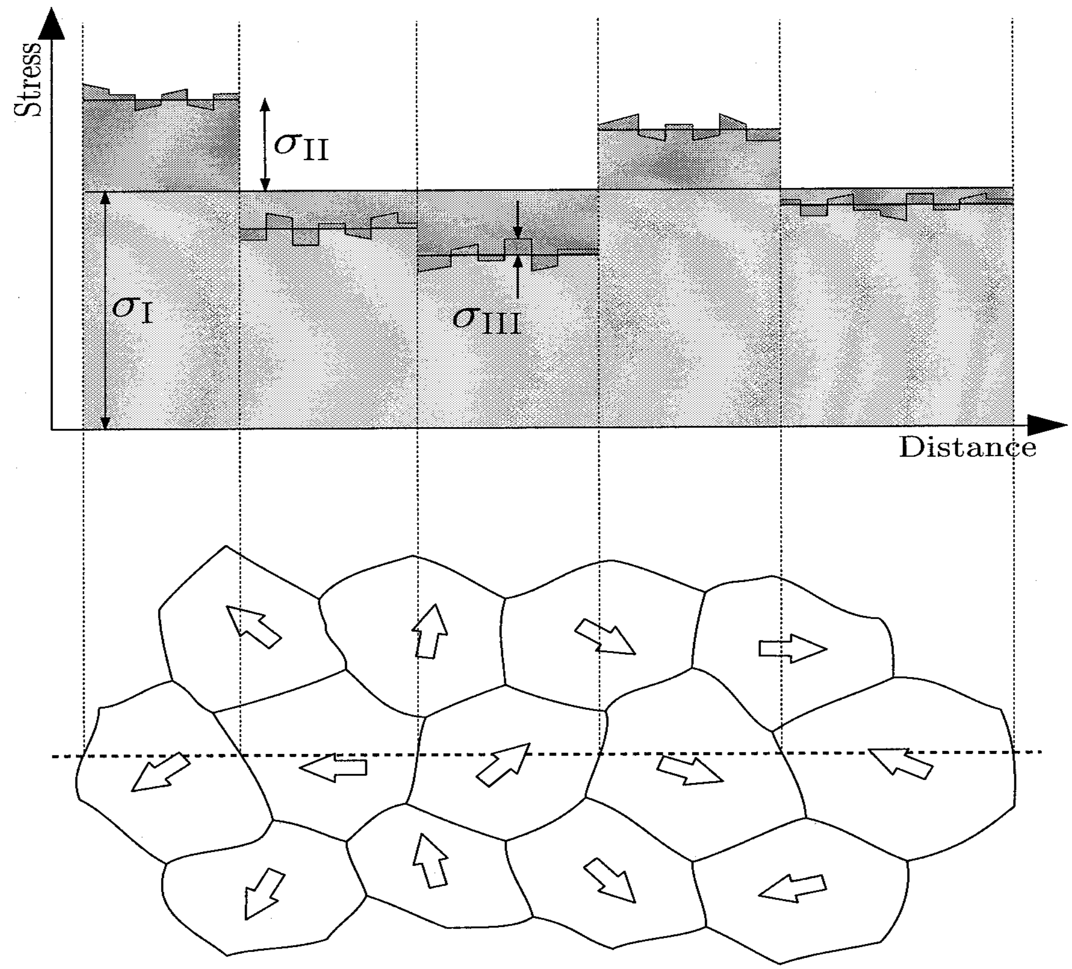
Origin of Intergranular Microstrains in Polycrystals

“Canonical” behaviour of low SFE Face-centred Cubic Polycrystals

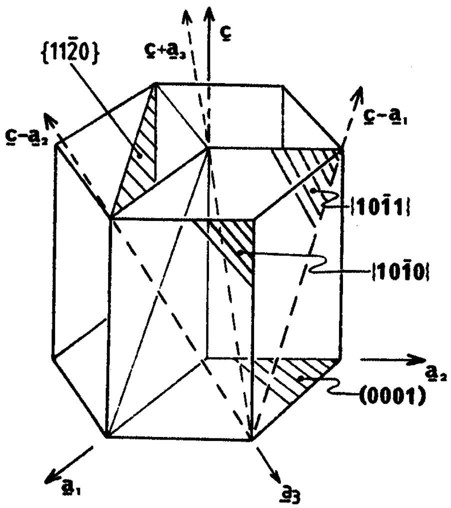


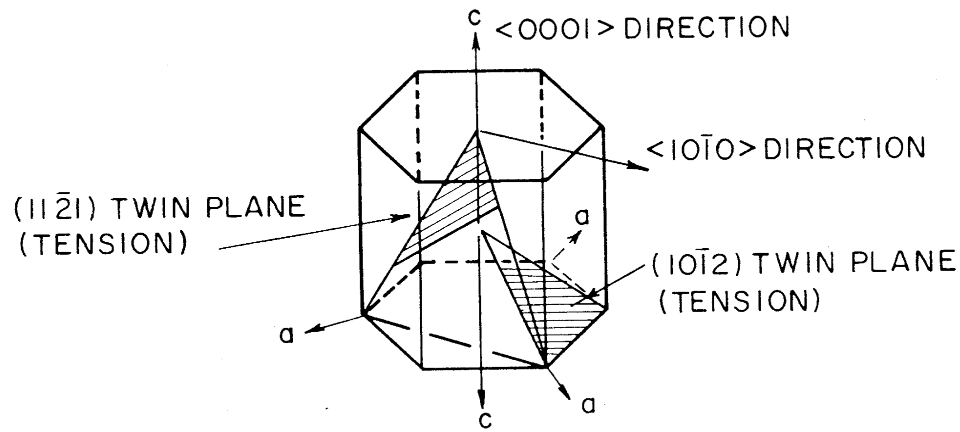
- Accumulation of elastic microstrains in polycrystals is observed to be orientation (hkl) specific
- Magnitude and sign of the residual elastic component upon removal of external load is determined by elastic and plastic anisotropy

Origin of Intergranular Microstrains in Polycrystals (cont.)



Plastic Anisotropy in HCP Metals

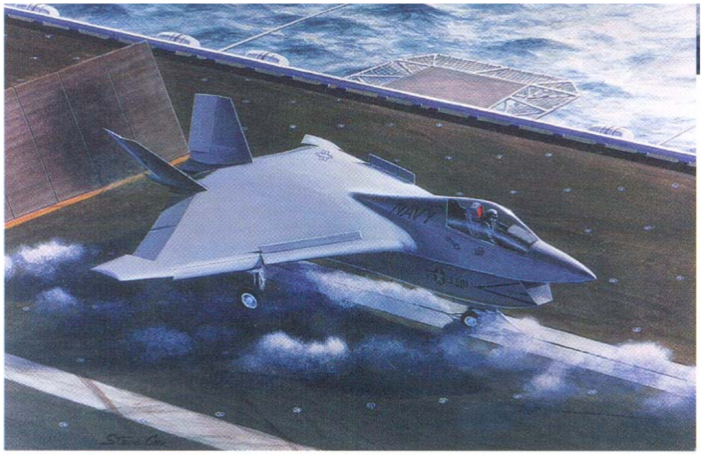


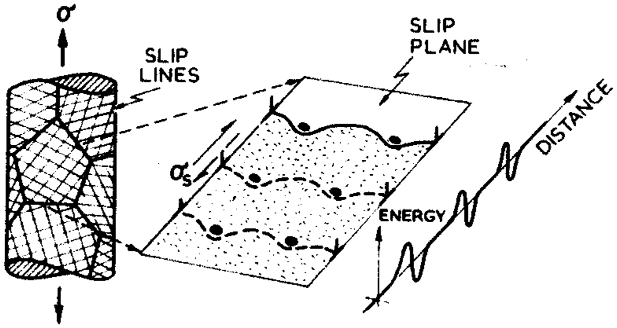


- Multiple slip and twinning mechanisms are observed in HCP crystals (5 slip, 2 twinning)
- 3 “softest” mechanisms ($\{0001\}\langle 11\bar{2}0\rangle$,$\{10\bar{1}0\}\langle 11\bar{2}0\rangle$,$\{10\bar{1}1\}\langle 11\bar{2}0\rangle$) cannot activate slip in the “c” axis orientation
- Shear Stress which activates a particular slip or twinning is not known for most alloys

Goals of this research

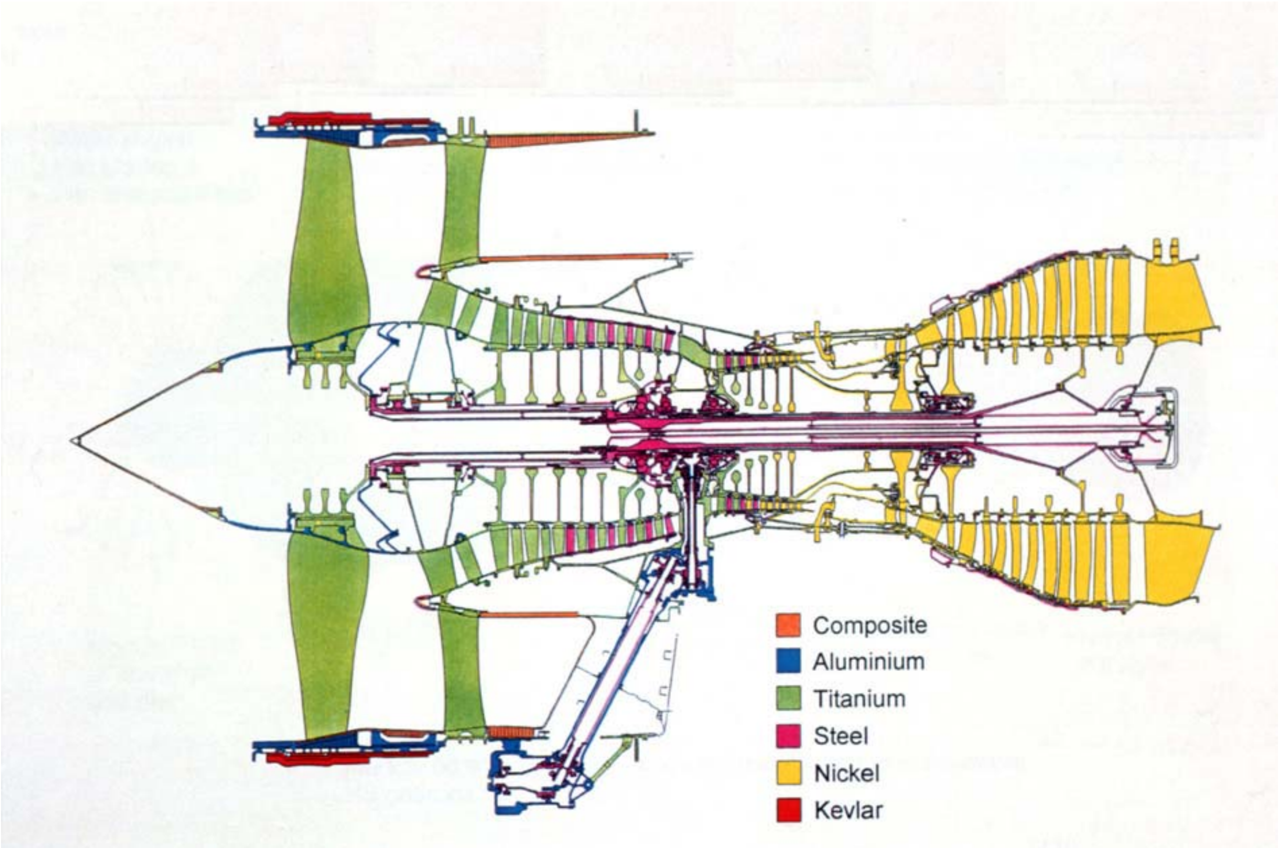
- Identify crystal planes in a technologically relevant HCP alloy which are suitable for diffraction based residual stress measurements
- Rationalize observations of residual microstrain with models of polycrystalline plasticity
- Advance our understanding of deformation of HCP polycrystals in general





Aeroengine Components Fabricated From Ti alloys

Materials in Rolls Royce Trent 800 series



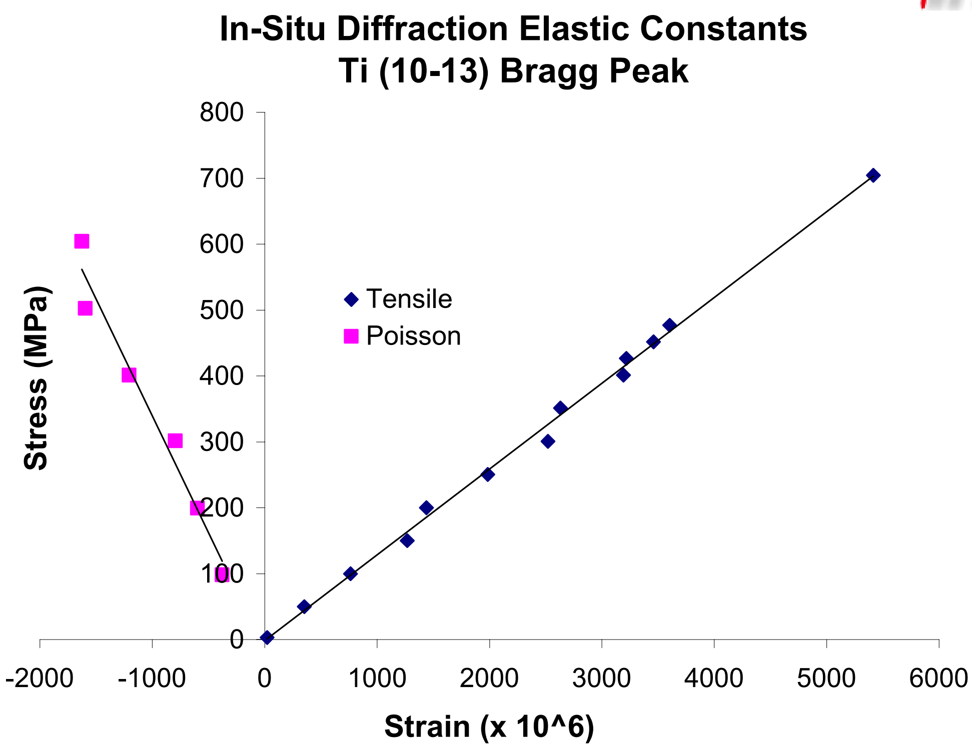
Microstructure of IMI - 834

- Ti alloy 834 (5.5 % Al, 4% Sn, 4% Zr, 0.3% Mo, 1% Nb, 0.35% Si)
- Strong (UTS 1 GPa at RT), creep resistant up to 600°C
- As-received stock: 4 mm thick plate cut from forged disk
- No preferred orientations!

Base, 200x

In-Situ Deformation Experiments: Elastic Regime

- Stress-Strain data in the elastic regime are necessary to account for elastic anisotropy of the crystallites
- Obtained data from 16 loading experiments (1 tensile, 1 Poisson * 8 hkl reflections) and fit to a Kroner model

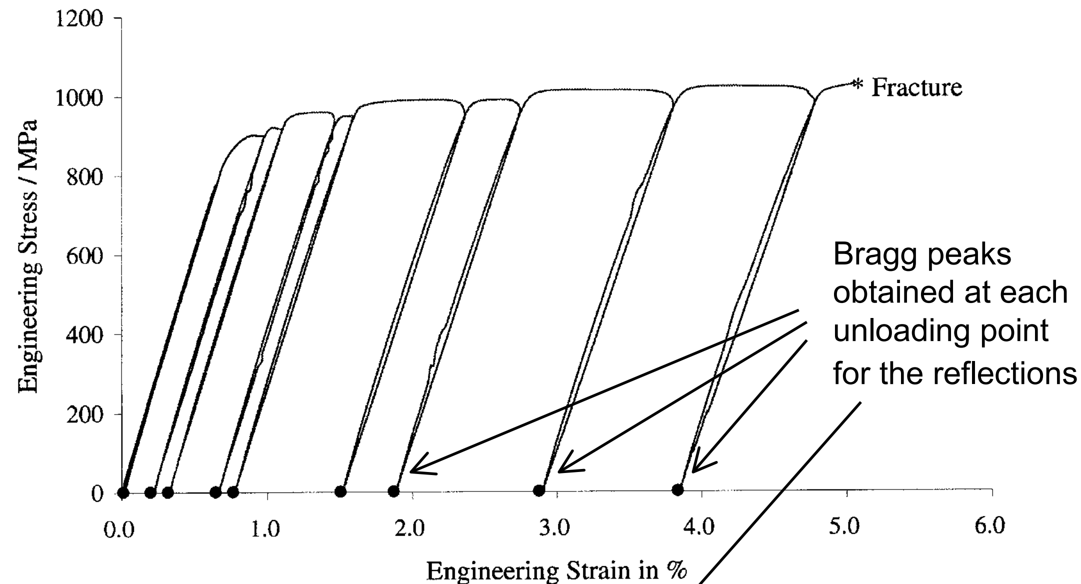


	C_{11}	C_{33}	C_{44}	C_{12}	C_{13}	Refs.
Model	168.0	190.5	48.8	94.5	69.3	-
Literature	160.0	181.0	46.5	90.0	66.0	[8]

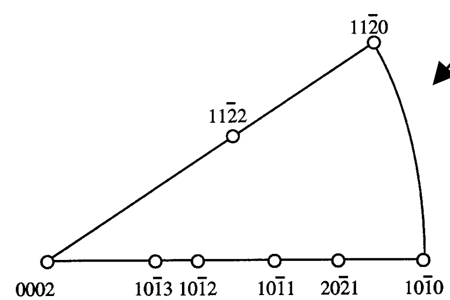
- Measured elastic constants are in excellent agreement with pure Ti

In-Situ Deformation Experiments: Onset of Yield and Plastic Flow

- ND measurements performed during tensile tests of “dogbone” specimns cut from a large forging

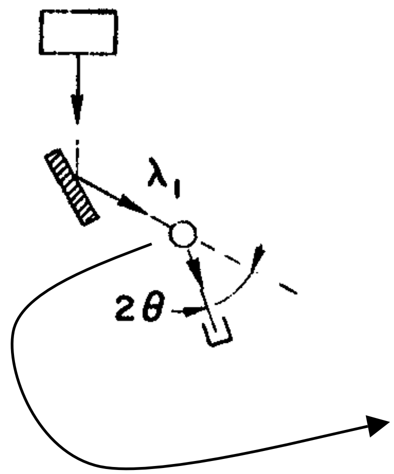


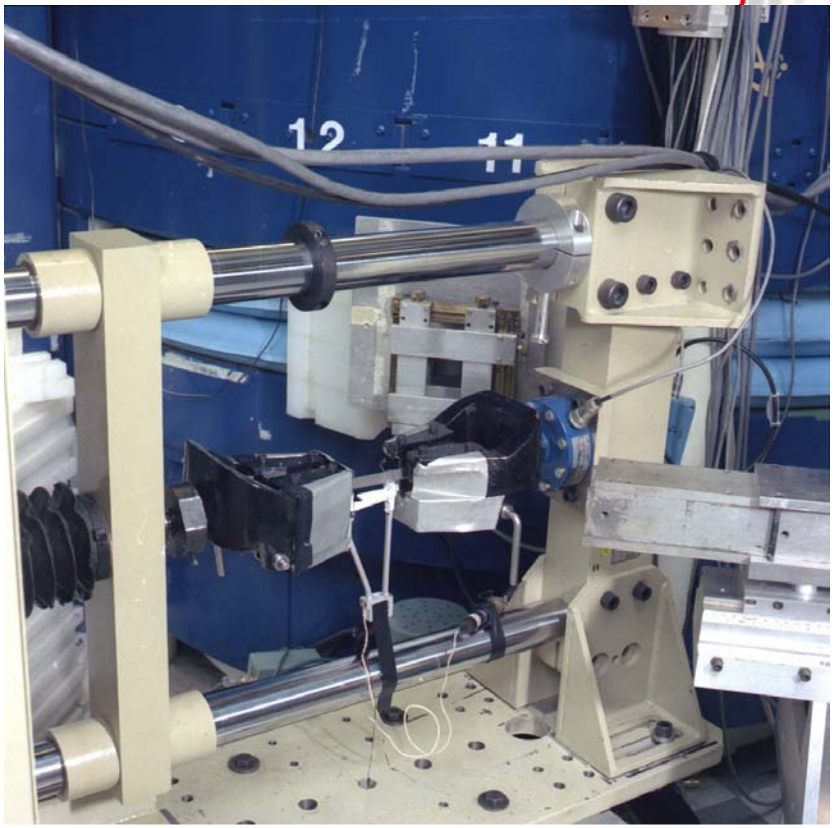
- The development of residual microstrains in 8 Bragg reflections were observed in the tensile and Poisson orientations

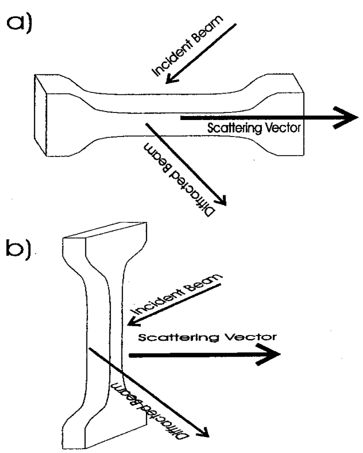


Experimental Configuration – Chalk River

- θ-2θ Scans performed in conventional 2-axis mode

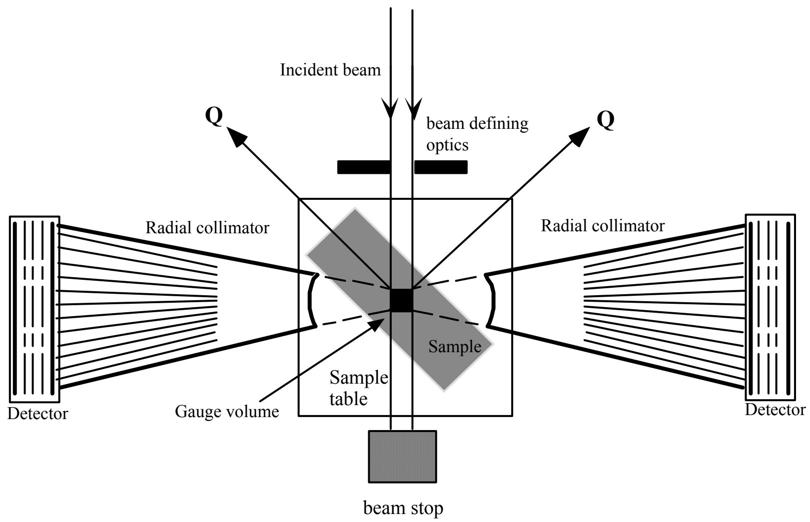


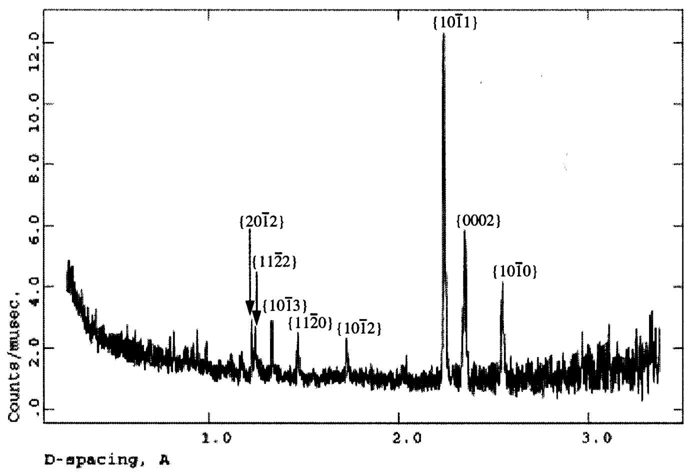


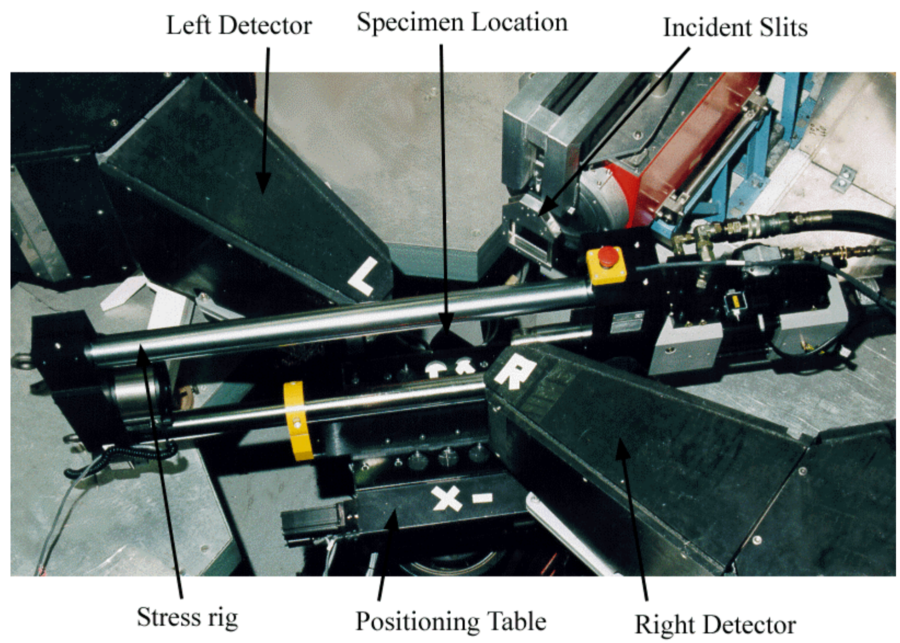


Stress Rig is re-oriented to collect data in Q // Poisson Orientarion

Experimental Configuration - ISIS







- **TOF permits the collection of a pattern (0.5 ~ 4.0 Å) in two Q's (tensile + Poisson) simultaneously**

Modelling: Basics of EPSC method

- Strain rate in a Titanium grain embedded in a homogeneous Ti matrix is related to the overall strain rate by:

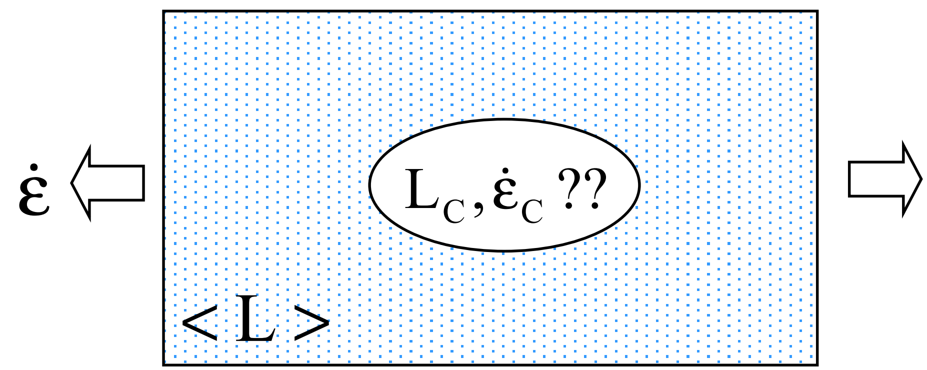
$$\dot{\varepsilon}_C = A_C < \dot{\varepsilon} >;$$

$$A_C = \Lambda^{-1}(\Lambda^{-1} + L_C - < L >)^{-1}$$

where; Λ= Eshelby Tensor

L_C, <L> = Effective stiffness of inclusion, surrounding medium

P.Turner and C. Tomé (1994), *Acta Metall.*, v. 42, 4043



- Effective, instantaneous stiffness of each grain L_C is formulated in a pseudo-linear expression:

$$L_C = L_e(I - \sum_i \sum_j m^i Y^{ij} m^j L_e)$$

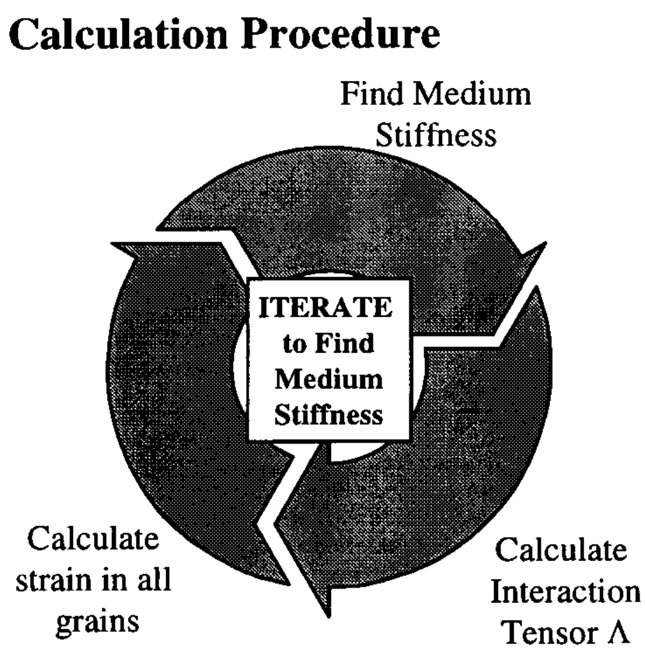
Elastic Stiffness Matrix

Terms allow for softening due to slip mechanisms

Basics of EPSC (cont.)

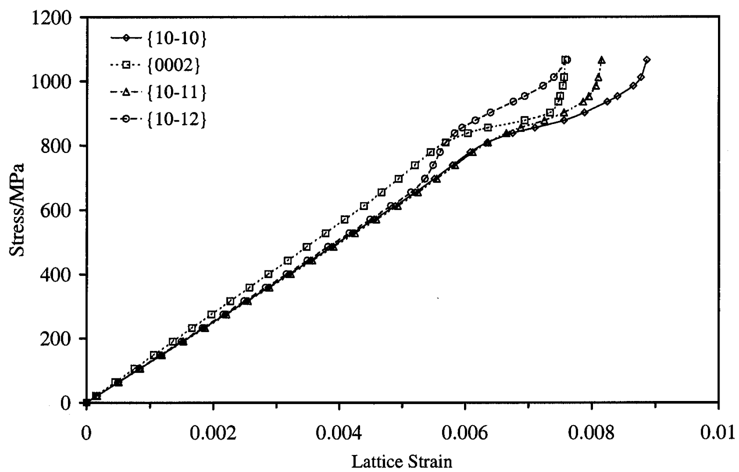
- Collective Behaviour of 3000 randomly oriented grains are simulated
- Stiffness of the “effective medium” subject to the boundary condition:

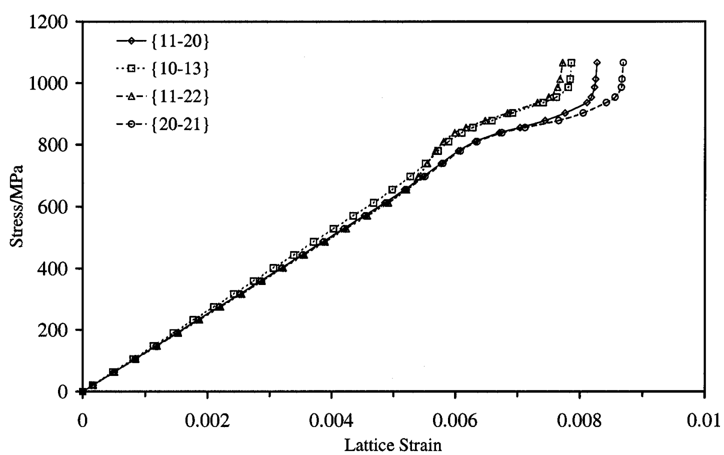
$$< L > = < L_C A_C >$$



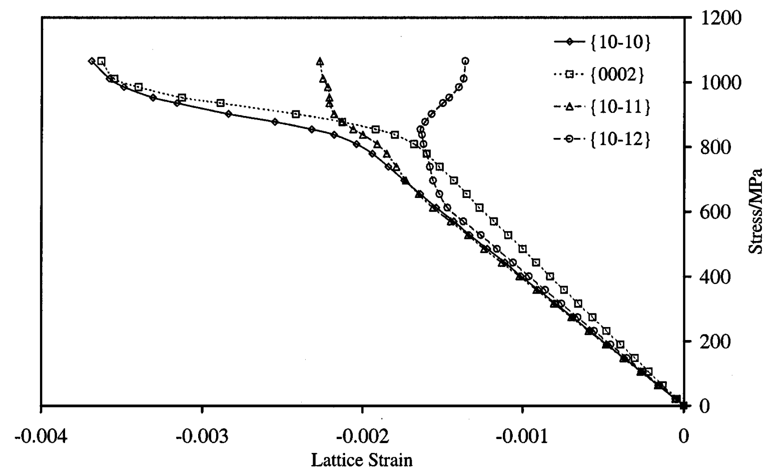
EPSC simulations

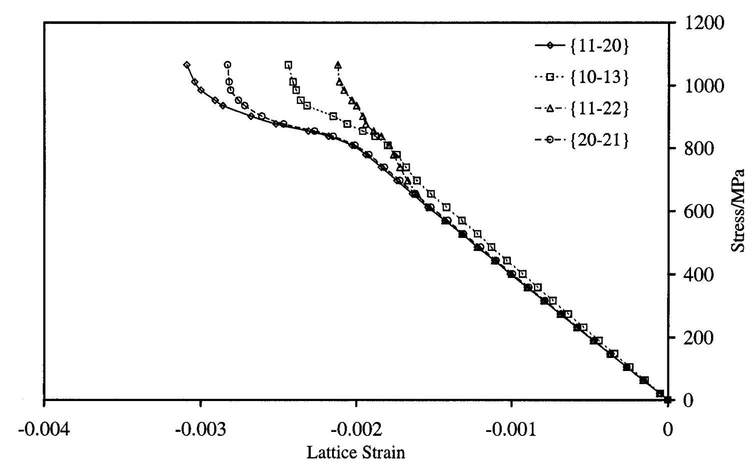
EPSC, Tensile





EPSC, Poisson

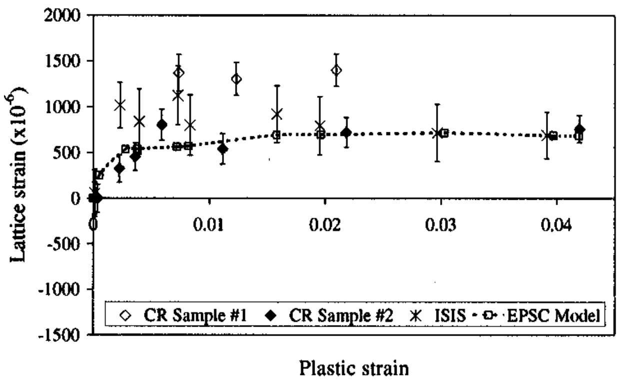




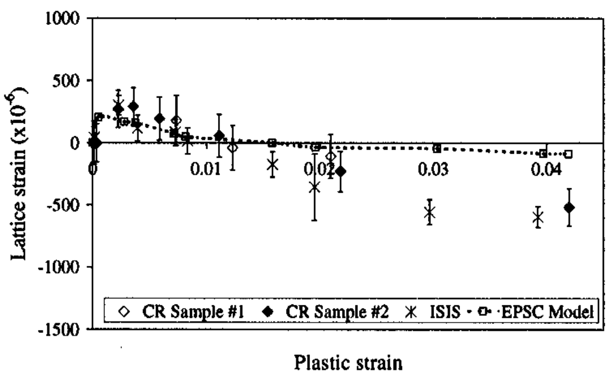
Model Results vs. EPSC

Tensile Orientation

$\{10\bar{1}0\}$

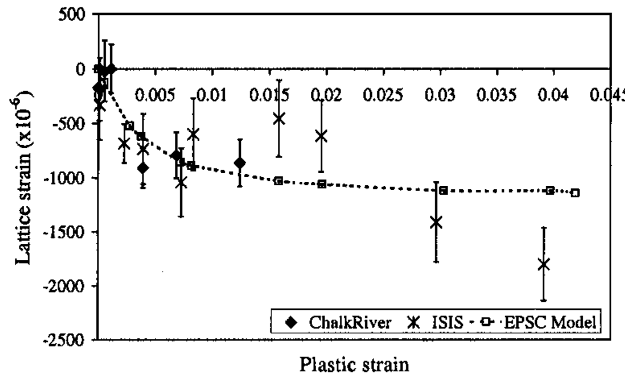


$\{10\bar{1}1\}$

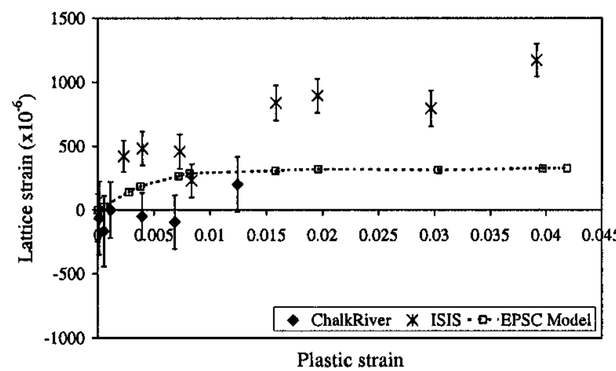


Poisson Orientation

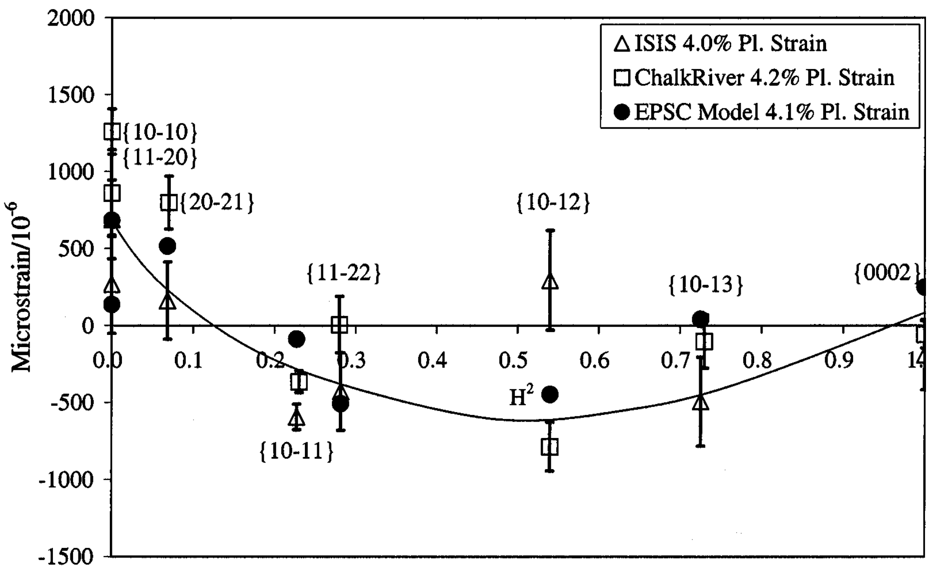
$\{10\bar{1}0\}$

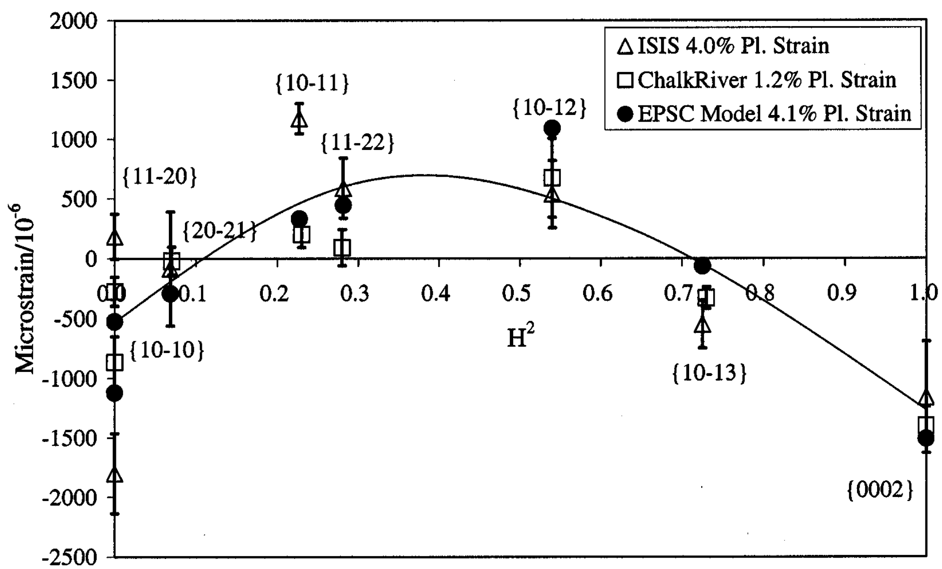


$\{10\bar{1}1\}$



Model Results vs. EPSC (cont)



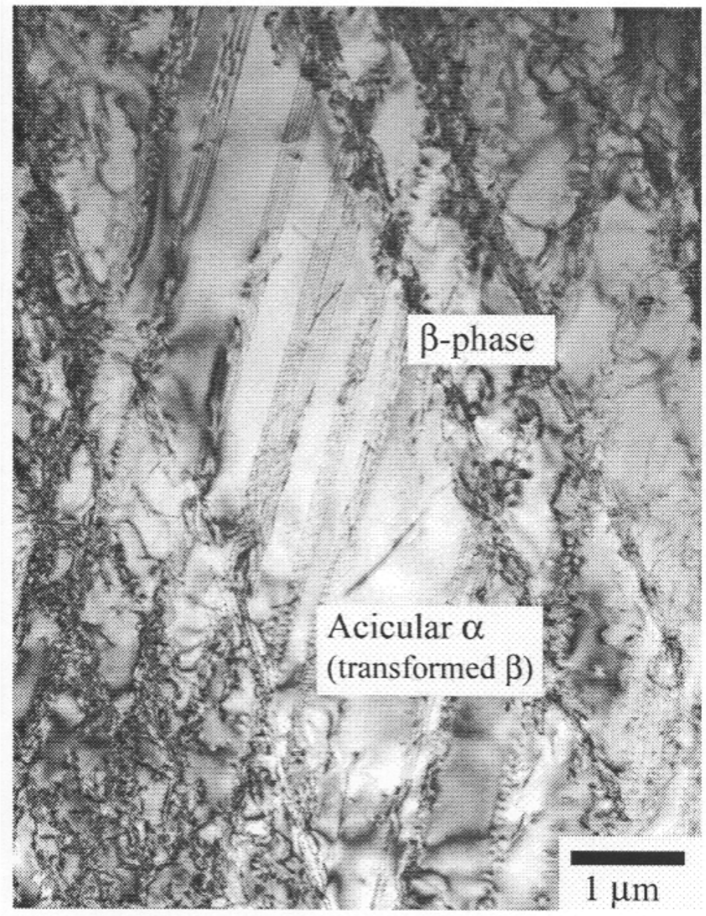


- CRSS of 5 slip systems were adjusted to yield best fit to flow curve and residual microstrains

Slip system	CRSS (MPa)
$\{0002\},\langle 11\bar{2}0\rangle$	300
$\{10\bar{1}0\},\langle 11\bar{2}0\rangle$	400
$\{10\bar{1}1\},\langle 11\bar{2}0\rangle$	450
$\{11\bar{2}2\},\langle 11\bar{2}\bar{3}\rangle$	550
$\{10\bar{1}1\},\langle 11\bar{2}\bar{3}\rangle$	600

TEM observations

- Specimens tested to failure show no evidence of twinning in optical and TEM micrographs
- Past ND experiments on Mg suggest twinning may be correllated with changes in peak intensity as a function of applied strain; no evidence of intensity variations were observed here



Summary

- In-situ diffraction experiments were conducted during deformation experiments on Ti alloy 834;
- EPSC model was implemented to attempt to rationalize observed residual microstrains in 8 Bragg reflections in tensile and Poisson orientations;
- Good agreement is obtained with a model which allows for 5 slip systems;
- Samples deformed to failure show no evidence of deformation twinning;
- Future experiments on Ti should examine microstrains as a function of alloying (e.g. Al) in simple model systems; increases in Al solute are known to supress twinning.